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(58) Field of search
H4D

(54) Detecting objects in obscuring medium

(57) To detect and range objects which are concealed in an attenuative medium, such as submerged submarines, light pulses back-scattered by the medium are examined for sudden discontinuities, an object being shown to be present when one occurs. Since an object will effectively prevent further back-scatter. This allows for the use of longer laser pulses.

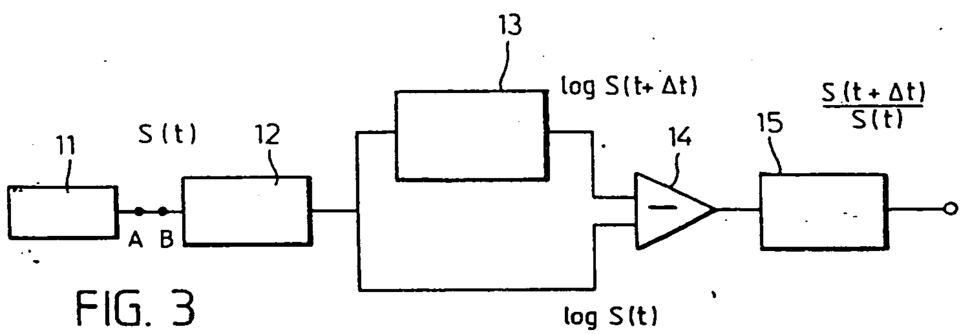


FIG. 3

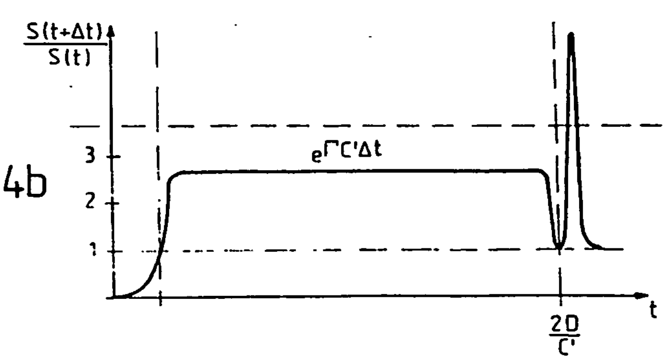


FIG. 4b

GB 2 161 340 A

FIG. 1a

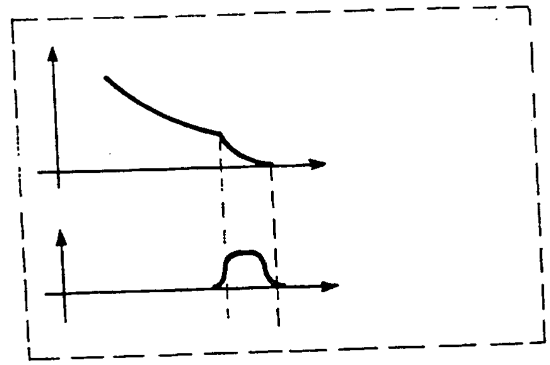


FIG. 1b

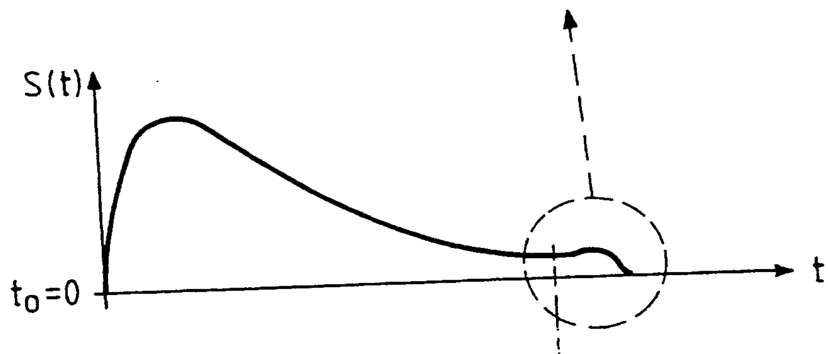
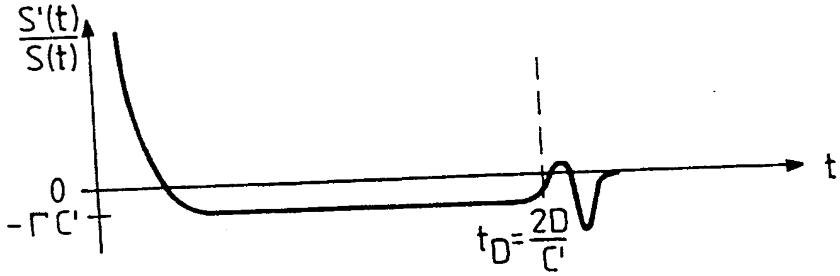


FIG. 2



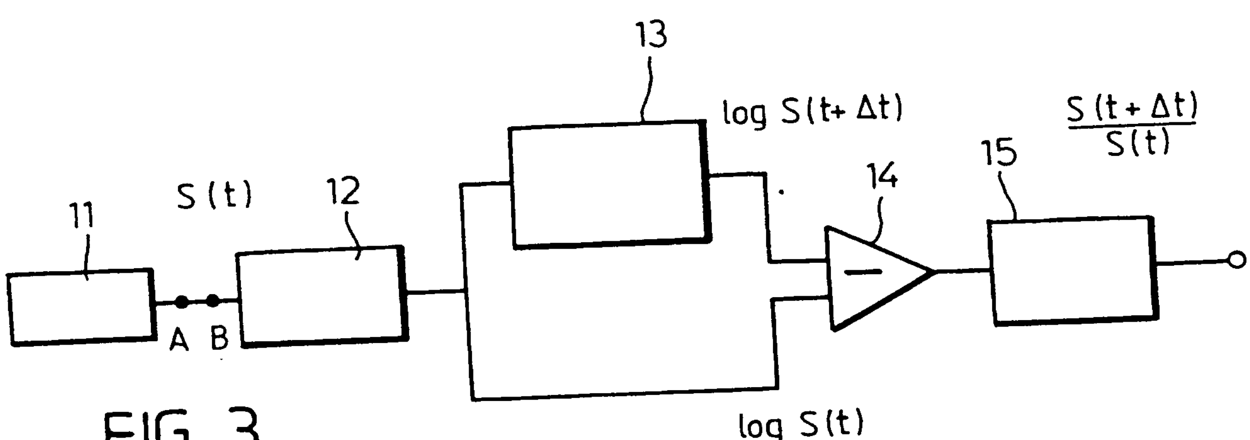


FIG. 3

FIG. 4a

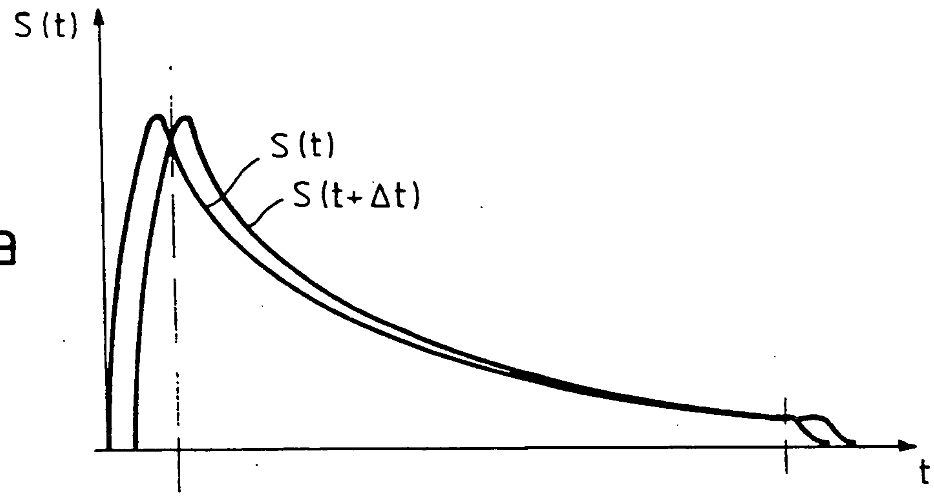


FIG. 4b

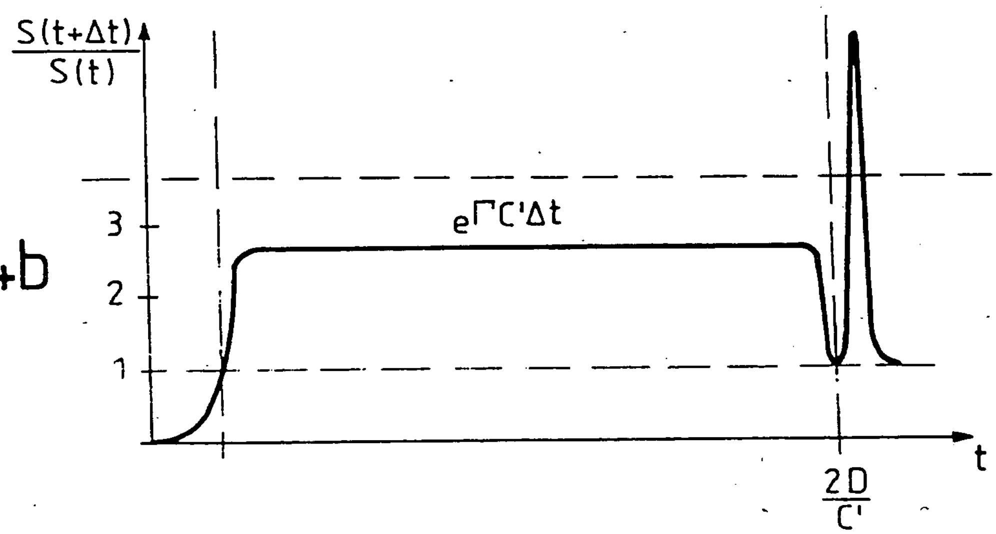
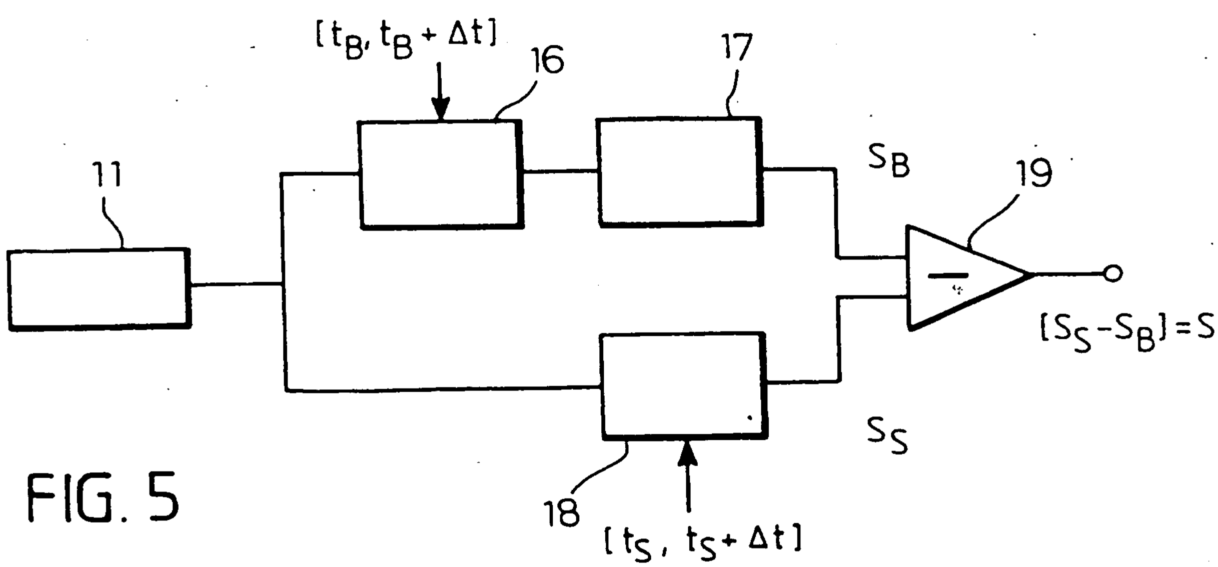


FIG. 5



SPECIFICATION

Method and apparatus for detecting, distance-gauging and imaging objects in a turbid surrounding media using a laser

This invention relates to a method and apparatus for detection, distance-gauging and imaging objects which may be either absorptive or reflective and which are concealed in a medium which is highly attenuative as a result of light dispersion, the method using a pulsed laser as the radiation source.

In the method the primary light beam along the transmission path is considerably attenuated by scatter and accompanied by interfering scattered signals from the medium itself.

In DE 26 34 627, DE 31 03 567 and DE 32 19 452 distance measuring systems are known which determine the time interval between a short reference laser pulse and a largely identical measuring pulse formed from the scatter light of the target object. In these systems the measuring error in the adaptation of the time interval is to be kept to the minimum.

The range of long distance laser measuring methods in the atmosphere or through sea water, using laser radar, lidar and laser range finders, is known to be far more dependent on the degree of turbidity of the transmission medium than with micro-wave or millimetre radar or accoustic echo-sounding processes. This circumstance is a particular drawback for military applications where targets usually have to be detected rapidly and accurately under difficult visibility conditions. This only refers to the usual systems based on the so-called echo or pulse time principle, in which short pulses or pulse trains are sent from a laser transmitter to the target with a receiving device being provided coaxially or parallel to the transmission axis and receiving the reflected pulse, the returns being evaluated, according to the requirement either in area scanning systems as an image point or in fixed axis systems as a distance, using a delay time measuring unit.

The detection of laser echo signals after beam propagation in turbid media is impeded by two factors; firstly the considerable attenuation or exponential decrease of the signal on the outward and return journay through the medium, makes it necessary to control high range signal dynamics, and secondly the considerable back-scatter in the medium itself, which occurs along the track of the pulse to the target and which in view of the non-uniform time characteristics generates signals often difficult to distinguish from the echo signals from the surface of the target.

This invention seeks to provide a considerable improvement in the detection probability and suppression of false-alarm probability in laser radar scanning systems such as used for detecting submarines from aircraft or for finding ground targets in poor visibility atmosphere, and with complete detection of not only the usual weak reflection from the object but also the frequently far greater alteration in the back scatter of the medium such as water and/or air.

According to this invention there is provided a method for the detection, distance-measuring and imaging of objects which may be absorptive or reflective and which are concealed in a medium which has highly attenuative properties through light dispersion, the method using a pulsed laser as the radiation source, in which the back scatter signal from the medium being scanned using a pulsed laser beam is recorded in such a way that the entire back scatter is used for the detection of an object present in the medium and the detection system only responds to a signal discontinuity which is significant for the object.

According to this invention there is also provided apparatus for carrying out the method as above, wherein the time-resolved signal from a photo-receiver is conveyed through a logarithmic amplifier and then divided into two paths, in the first of which the signal undergoes a defined delay in a delay line in relation to the underlayed signal in the second path, after which both signals are fed to a differential amplifier which produces the difference between the two logarithmic signals in order to subsequently form the quotient of the two signals using an analog amplifier.

The invention is further described and illustrated with reference to the accompanying drawings showing an embodiment by way of example only. In the drawings:

Figure 1a shows a diagram of the scatter signals from a transmission medium and object,

Figure 1b shows a diagram of the entire scatter signal as a function of time,

Figure 2 shows a diagram of the standardised time derivative of the signal,

Figure 3 shows a block diagram of the signal evaluation unit for forming the quotient of delay signal and direct signal,

Figure 4a shows a diagram of the direct and the delay signal,

Figure 4b shows a diagram of the time characteristics of the quotient of delay signal and direct signal, and

Figure 5 shows a block diagram of the signal evaluation unit for subtracting the optical background from the wanted signal.

In order to clarify the functioning of the method and advantages as compared with conventional methods the time-governed back scatter signal of a laser radar system from a turbid medium is first considered as shown in Figure 1b. At the moment t_o, here expressed as $t = o$, is the beginning of the back scatter signal from the rising edges of the short pulse in the medium such as surface of the sea or bank of fog as detected by the laser receiver. During the penetration of the pulse into the medium the signal,

due to the back scatter from the medium, continuously rises to a maximum, where the pulse is now fully within the medium. As the period continues the signal decreases exponentially with the time,

$$S(t) \sim e^{-\Gamma C' t} \qquad (1)$$

wherein Γ is the attenuation coefficient of the medium and C' the speed of the light in the medium. At the instant

$$t_D = \frac{2D}{C'}$$

as seen by the receiver) the pulse rise edge has reached an object at range D, where two things occur as the period continues: In the first place the back scatter from the medium decreases in a time corresponding to the pulse width t_*, to zero (see Figure 1a), and in the second place the surface of the object reflects or disperses part of the pulse energy back again, this signal assuming over the period exactly the same form as the pulse emitted, as may be seen from Figure 1a. The two signal changes together result in the course shown in Figure 1b.

$$(t_D) = \frac{D^{Medium}(T_D)}{S^{Object}(t_D)} = \frac{\pi \Gamma (\pi)}{2\Gamma_{r}} = [e^{\Gamma C' t_*} - 1] \qquad (2)$$

wherein $\beta(\pi)$ is the back scatter coefficient and ρ the degree of reflection of the object.

An arithmetic evaluation of this equation by the insertion of known data for $\beta(\pi)$ and Γ for different types of turbid media shows that the signal change of the back scatter is significantly higher than the object reflection in media with an attenuation $\Gamma \geq 0{,}1\ m^{-1}$, a ratio $\beta(\pi)/\Gamma \geq 10^{-2}\ sr^{-1}$ and a pulse time $t_* \geq 0{,}1\ m^{-1}$, a ratio $\beta(\pi)/\Gamma \geq 10^{-2}\ sr^{-1}$ and a pulse time $t_* \geq 5ns$. It should be added that the reflection from an object is usually dispersed isotropically in all spatial directions, where only a small proportion enters the field of vision of the receiver. This is a different situation from that applying to the back scatter of the medium which usually shows a pronounced radiation lobe in the rearward direction with an angle of aperture of only a few degrees thus a correspondingly high proportion of stray light enters the field of vision of the receiver.

A comparison with the known data for turbid sea water and artificial fog, such as a military smoke screen shows that with wave lengths in the visible and near IR range this ratio is clearly above 1. An example is provided by typical data for coastal water in the Baltic, with $\Gamma = 0.25\ m^{-1}$ and $\beta(\pi) = 10^{-1} m^{-1} sr^{-1}$. With a pulse length of $t_* = 30ns$ for the laser and a degree of reflection of $\rho = 0.1$ for the object sought, we find that $\varepsilon_o = 33$.

This result shows that by the use of relatively long laser pulses and a signal evaluation apparatus designed to detect signal changes over periods corresponding to the length of the laser pulse it is possible to obtain far clearer signal echos from objects than with short-pulse methods.

This improvement in the detection of objects involves some sacrifice of accuracy in determining the distance between object and receiver, the accuracy being proportional to the laser pulse time. In this case, however, the range-finding accuracy can be restored by averaging a number of individual measurements over a pulse train.

As the usual signal evaluation apparatus is designed for the use of as short pulses as possible, with a higher peak performance and the corresponding short reflections from the object, an apparatus is proposed which will be eminently suitable for the aforementioned detection of the relatively long scatter signals. Surprisingly enough, this object is achieved by the simple expedient of forming the quotient of the delay signal and the direct signal, the delay having to be adapted to the attenuation values of the medium and the pulse time of the laser.

The simplest way of explaining this new method is to compare it with the method which has usually been adopted.

Owing to the high dynamics of the received signals the signal amplification is usually adjusted upwards, after reflection of a laser pulse, from a low value to increasingly high values, in accordance with the pulse transit time. This operation is generally performed using an amplifier with a logarithmic characteristic, that is by forming the natural logarithm of the time-governed reception signal S(t). By this operation the original signal which decreases exponentially in the dispersive medium made is linear, that is from the decrease $e^{-\Gamma C' t}$ we obtain $-\Gamma C' t$. In order to detect the reflection or the rapid decay of the signal at the target object the signal is also differentiated. The signal then having a linear characteristic from the dispersive medium but a transient from an object, as shown in Figure 2.

From the equation

$$\frac{d \log S(t)}{dt} = \frac{S'(t)}{S(t)} \qquad (3)$$

it may be seen that the resultant signal represents the standardized time derivation of the received signal (the instantaneous slope of the signal curve). Finally the signal disturbance from the object is detected by recording the passage through zero or by raising the signal above a fixed signal discrimination level.

This method of signal evaluation is suitable for the detection of very rapid signal changes, (rise or fall of the signal) but reacts almost indifferently to relatively slow changes in the course taken by the signal.

If the usual course taken by the signal on the object in a highly dispersive medium is now considered, as shown in Figure 1b, it is a noticeable fact that the change in the slope of the signal curve is relatively small at the time when the rising pulse flank encounters the object, by comparison with the change occurring while the falling flank is encountering the object surface, where the signal decreases from the peak value to zero. This means that in the signal evaluation process described in the foregoing the main effect is exerted by the falling flank of the laser pulse and the main requirement is that this fall should take place in as short a time as possible and that the peak performance of the pulse should be at its maximum.

For reasons of balance of performance, however, this situation is unsatisfactory, for only half the laser pulse takes effect in the useful received signal. The method suffers from the further drawback that it responds to all brief signal changes, so that with the slightest unevennesses in the scatter on the way to the object additional interference signals are picked up which cannot be easily distinguished from the signal from the object.

In order to overcome these drawbacks and to render the whole of the signal usable as far as possible whilst at the same time keeping the probability of interference to the minimum, the invention proposes a signal evaluation apparatus such as that shown in Figure 3. The signal from the detector 11 is first of all passed, as normal, through a logarithmic amplifier 12. It is then divided into two signal branches, the first of which passes through a signal delay device 13, so that it will acquire a fixed delay Δt in relation to the direct signal in the second branch.

The two signals logs S $(t + \Delta t)$ and log S(t) are now substracted from each other using a differential applifier 14. This operation gives the logarithm of the quotient of the two signals, while the subsequent inversion function of an analog amplifier 15 leads to the quotient.

$$\varepsilon(t) = \log^{-1} \log \frac{S(t + \Delta t)}{S(t)} = \frac{S(t + \Delta t)}{S(t)} \qquad (4)$$

The direct and the retarded signal are shown together in Figure 4a and their ratio ε (t) in Figure 4b. As may be seen from Figure 4b, ε (t) increases from zero through 1 (where the two signals intersect) as far as a constant value $e^{c \cdot \Delta t}$, before the laser pulse encounters the surface of the object.

In the period before the laser pulse encouters the surface of the object there is generally an initial slight increase of the direct signal by reason of the additional proportion of object scatter. In the same period, however, the delay signal is still decreasing, that is the ratio increases up to a maximum. As the period continues both signals decrease to zero and the ratio to 1.

If the delay Δt selected is made about equal to the pulse length t_*, the entire change of the signal on the object will naturally take effect in the transient of the quotient. A reference moment where the pulse encounters the object can be defined by all the customary methods, such as signal maximum detection, pulse heights, discrimination, pulse centre definition, etc.

A genuine comparison between this method and the method previously mentioned is obtained if *1* is subtracted from the ratio ε (t), which does not interfere with the course taken by the signal curves:

$$(t) - 1 = \frac{S(t + \Delta t)}{S(t)} - 1 = \frac{S(t + \Delta t - S(t)}{S(t)} \qquad (5)$$

From this expression it may be seen that the course taken by the curves represents the standardized signal difference between the retarded and the direct signal, the standardized derivation from above can be obtained by

$$\lim_{\Delta t \to 0} \frac{[\varepsilon(t)-1]}{\Delta t} = \frac{S'(t)}{S(t)} \qquad (6)$$

The main advantage of this process by comparison with the usual methods resides in the fact that it can be used with a delay correctly selected for both short and long pulses, using the entire signal change resulting from object reflection and cessation of back scatter in the medium. A further advantage is to be found in the fact that signal interference due to unevennesses in the dispersive medium can be averaged by correct adaptation of the delay Δt.

As in all laser distance-gauging methods for daytime use in the atmosphere, this method also suffers interference from background. This invention therefore provides for an effective optical suppression of the background using interference filters with a cut-off range outside the laser wave length. In addition it provides for electronic elimination of the background level by means of a signal subtraction device such as shown in Figure 5.

With this circuit the intermediate periods are inserted between the measuring times of the background radiation and the signal current of the background, by a delay line 17 provided for the measuring signal of the next measuring period 16,18, in order to switch one measuring line or the other into the circuit in alternation. This is interposed between the photo-receiver 11 and the log amplifier 12, at points A and B in Figure 3. The laser and the analog switch 16,18 are actuated at the appropriate times by means of a common impulser. The delay between the background signal measurement and the information signal measurement is marked χ, while the differential amplifier 10, by which the signal and the background signal are subtracted from each other, is marked 19.

CLAIMS

1. Method for the detection, distance-measuring and imaging of objects which may be absorptive or reflective and which are concealed in a medium which has highly attenuative properties through light dispersion, the method using a pulsed laser as the radiation source, in which the back scatter signal from the medium being scanned using a pulsed laser beam is recorded in such a way that the back scatter is used for the detection of an object present in the medium and the detection system only responds to a signal discontinuity which is significant for the object.

2. Method in accordance with Claim 1, wherein the back scatter signal received is split, one part being delayed and the quotient of the delayed and the non-delayed signals formed, the length of the time delay being variable and capable of being adapted to the attenuation value of the medium and the pulse duration of the laser.

3. Apparatus for carrying out the method of Claim 1, wherein the time-resolved signal of a photo-receiver is conveyed through a logarithmic amplifier and then divided into two paths, in the first of which the signal undergoes a defined delay in a delay line in relation to the undelayed signal in the second path, after which both signals are fed to a differential amplifier which produces the difference between the two logarithmic signals in order to subsequently form the quotient of the two signals using an analog amplifier.

4. Apparatus in accordance with Claim 3, wherein a signal subtraction circuit is interposed between the photo-receiver and the logarithmic amplifier, with the use of a switch means and by actuating two analog switches in two signal branches alternately, the signal strength of the optical background is fed onwards at a defined time before the emission of the laser scanning pulse through a signal delay line, which is designed so that during a pulse measuring time initiated by actuating the second analog switch the two signals, pulse and background, can be separated from each other using a differential amplifier.

5. Apparatus in accordance with Claims 3 or 4, wherein the background signal is suppressed by means of an interference filter with a cut-off range outside the laser wave length.

6. A method for the detection, distance measurement and imaging of objects as described herein and exemplified with reference to the drawings.

7. Apparatus for usein the detection, distance measurement and imaging of objects as described herein and illustrated in the drawings.

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